

Inland Empire Swimming Committee Event & Heat Display Board

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Abstract

The Inland Empire Swimming Committee consists of 19 clubs from parts of Washington and Idaho. All of the clubs share a single scoring system and transport it between meets in a custom-built trailer. The scoring system consists of a scoring computer, which runs a timer, handles incoming time signals, determines placing and sends this information to a scoreboard.

The scoreboard is actually a collection of single, 8.5' x 14" display boards containing anywhere from 1 to 10 of these individual boards. Because the Inland Empire Swimming Committee has only one of these display boards to use, the useful information is not displayed for a long enough time, namely, the event and heat numbers are displayed very briefly between matches. This results in swimmers and spectators missing their events and not knowing where they are in the meet.

The goal of the swimming scoreboard Senior Design team is to design and build an informational display system to display the current event and heat number for each event and heat. To accomplish this goal, we will employ a microcontroller to receive the data stream coming from the timing computer and to translate the event and heat numbers. We will then send this data on to a display driver that will be running five 7-segment displays. The five displays will present the event number (3 digits) and the heat number (2 digits).

1. Project Description

1.1. Project Background

The Inland Empire Swimming Committee consists of 19 clubs from parts of Washington and Idaho. All of the clubs share a single scoring system and transport it between meets in a custom-built trailer. The scoring system consists of a scoring computer, which runs a timer, handles incoming time signals, determines placing and sends this information to a scoreboard.

1.2. Problem Statement

The scoreboard is actually a collection of single, 8.5' x 14" display boards containing anywhere from 1 to 10 of these individual boards. Because the Inland Empire Swimming Committee has only one of these display boards to use, the useful information is not displayed for a long enough time, namely, the event and heat numbers are displayed very briefly between matches. This results in swimmers and spectators missing their events and not knowing where they are in the meet.

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1.3. Functions

Our project's primary objective is to display the event and heat information, with 3 sub-objectives. The first is Data Retrieval and Interpretation, the second is Data Transmission and the third is Data Display.

1. Data Retrieval and Interpretation:

- 1.1 Setup a microcontroller's serial port to receive the data coming from the timing computer.
- 1.2 Find the channel in the data stream that contain the event and heat number.
- 1.3 Interpret the hex values following the channel into the appropriate event and heat number.

2. Data Transmission:

- 2.1. Convert event and heat number to Maxim display format. Maxim receives 16 bits serial-data which contains register address and actual data .
- 2.2. Get the clock and chip select working. When chip select is active low, the data begins to be sent. One bit is sent on one clock, so 16 bits data need 16 clocks to be sent.
- 2.3. Send the setup codes which are the address of control registers. The control registers consist of shutdown mode, decode mode, and scan limit.
- 2.4. Send actual data which is the event and heat number. The first sent is digit15, the most significant bit.

3. Display the Data:

- 3.1. Obtain a display driver. We don't want to program the microcontroller to output the necessary signals to drive the displays..
- 3.2. Obtain appropriate displays. We need at least 5" displays, and we will need 5 of them.

3.3. Develop a power supply system to drive the displays, display driver, and microcontroller.

1.4. Means

1. Data Retrieval and Interpretation:

- 1.1 In order to receive the data stream, the microcontroller was setup to receive a serial signal with the same parameters as the timing computer; 9600 BAUD, 8 data bits, 1 stop bit and even parity. Please refer to Appendix A for further timing computer operation information.
- 1.2 Properly connect the datastream coming from the timing computer to the microcontroller. Since the microcontroller had a female serial connection, it received serial data on pin 3.
- 1.3 Only one program for the microcontroller to receive the data, decode the event and heat, and then send the display driver the proper signals. This program has two variables, event_num and heat_num that are updated whenever an incoming event and heat number are detected.

2. Data Transmission:

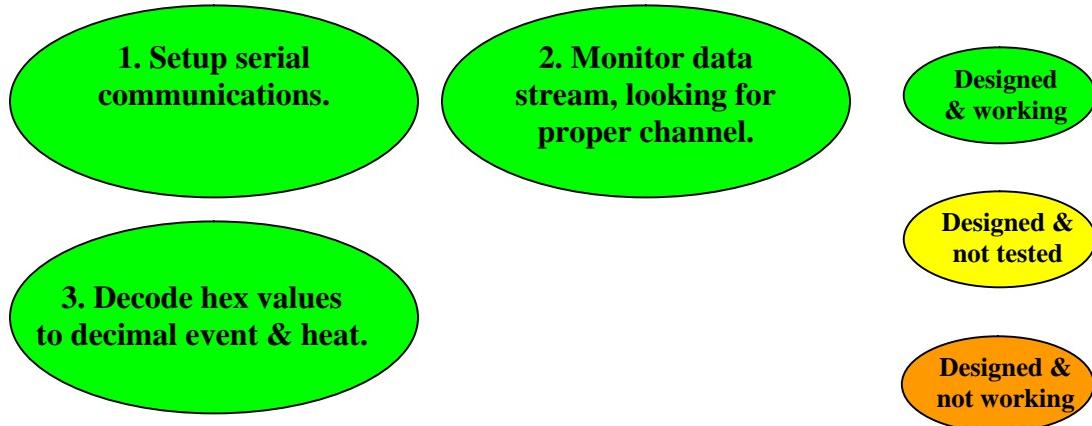
- 2.1 The Maxim display driver receives 16 bits serial-data which are labeled D0 – D15. D0-D7 contain the data which is one digit number(0-9), and D8 – D11 contain register address which assign 7 segment LED, and D12 – D15 are “Don’t care” bits. Refer to Appendix B for further information on how the Maxim display driver works.
- 2.2 Data will be sent to the Maxim using 3 transmission lines. Din (Serial-Data Input), CS’ (Chip-Select Input), and CLK (Serial-Clock Input).

3. Data Display

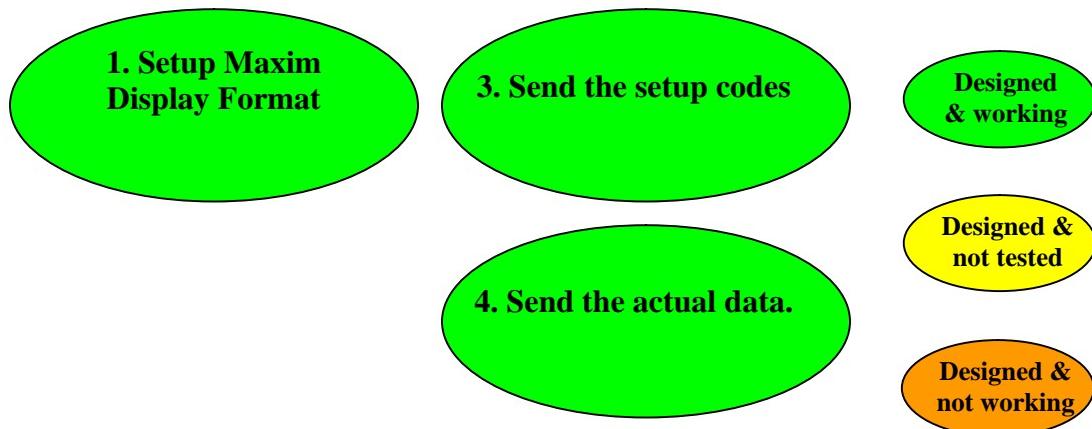
- 3.1 The five 7 segment displays will be connected to the Maxim display driver.
- 3.2. Voltage regulators will be used to convert the 120V AC input into the appropriate DC voltages for the Maxim chip and 7 segment displays.

2. Project Status

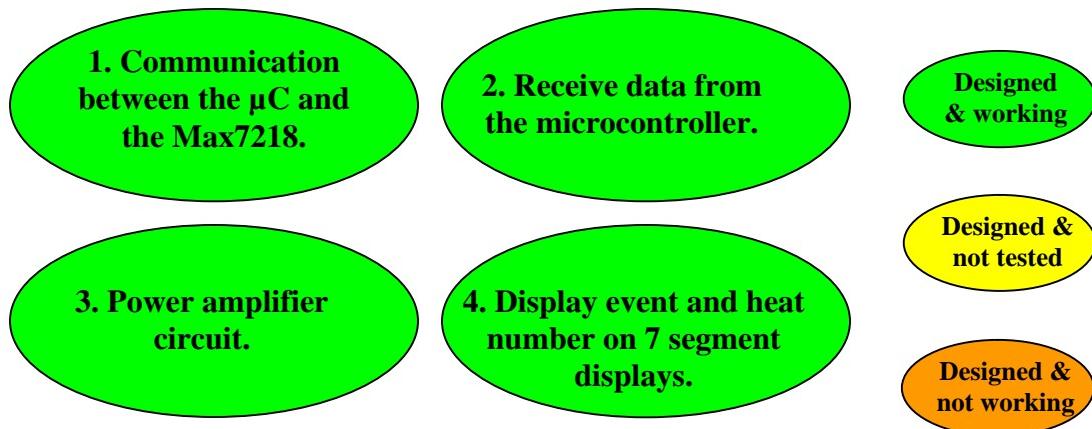
2.1. DATA RETRIEVAL AND INTERPRATATION



2.2. CONVERTING EVENT AND HEAT TO MAXIM



2.3. MAXIM AND 7 – SEGMENT DISPLAY SETUP



3. Method of Solution

3.1. Timing Computer Operation

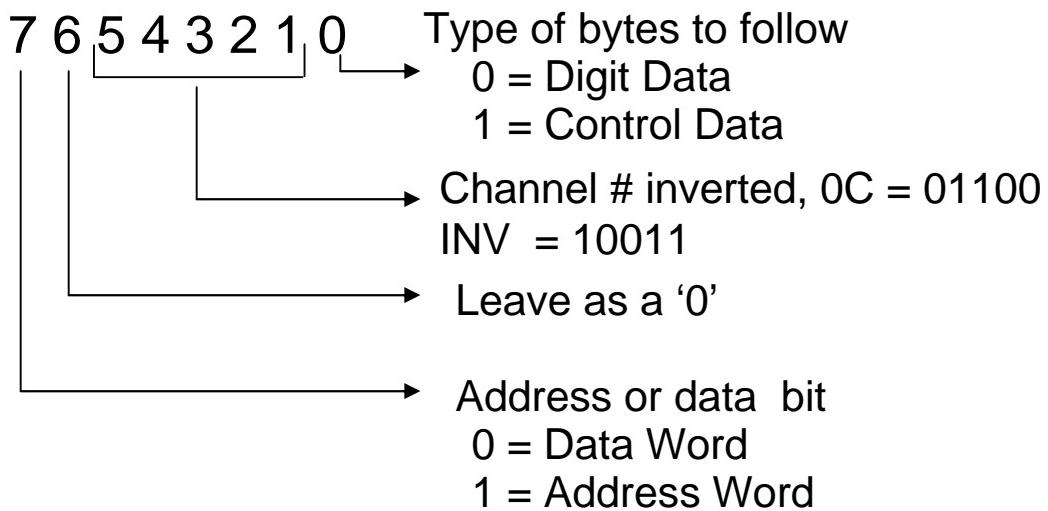
In order to explain the next part, converting the event and heat number to the hex codes that the timing computer sends to the scoreboard, let's take a side journey into how the timing computer works. The timing computer transmits data at 9600 BAUD, with 8 data bits, 1 stop bit and even parity. It cycles through 3 – 20 channels of information, sending 1 channel and the necessary data and then moving on to the next channel and so on. Each channel contains different data. See figure 1 for an example of the available channels.

Figure 1: Timing Computer Channels

LN	PL	TIME	Channel Number	EVENT	HEAT
1	8	88:88.88	01/11*	0C	888 888
2	8	88:88.88	02	HOME GUEST GUEST	888 88 888
3	8	88:88.88	03	0D/11*	1 2 3 4 5 6 7 8
4	8	88:88.88	04		8 8 8 8 8 8 8
5	8	88:88.88	05	0E	8 8 8 8 8 8 8
6	8	88:88.88	06	12**	8 8 88:88.88
7	8	88:88.88	07	HOME	G1 G2 G3
8	8	88:88.88	08	88	88 88 88
9	8	88:88.88	09	HOME	GUEST 1
0	8	88:88.88	0A	8888	8888
LENGTHS RECORD			0B	GUEST 2	GUEST 3
88 88:88.88			0B	8888	8888
			15	88:88	
			16	88:88	

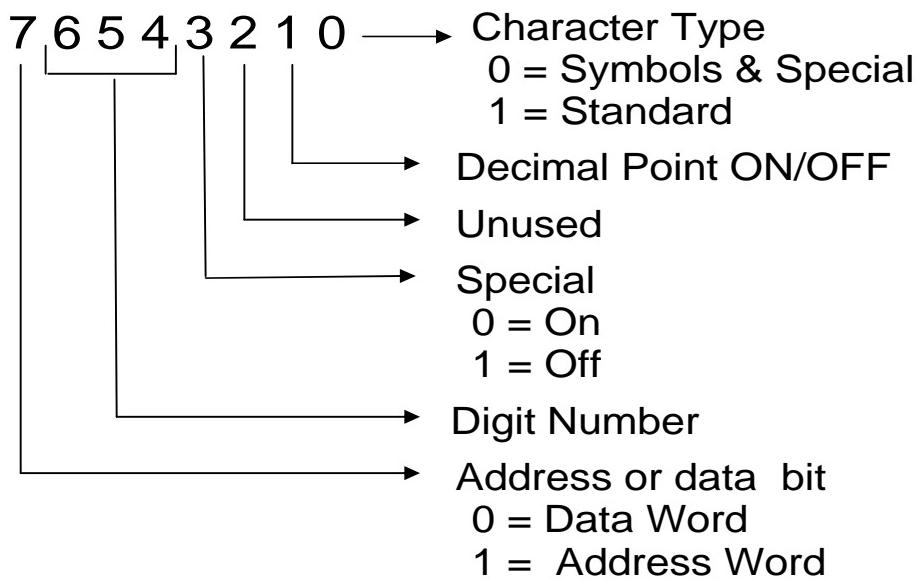
Channel 0C contains the event and heat data. When the timing computer sends out the event and heat number it first sends an address byte. The address byte tells us which channel the following data is for. The least significant bit of the address byte tells the scoreboard what type of information is coming next, control data or digit data. See figure 2 for the bit definitions for the address byte.

Figure 2: Address Byte Configuration



^The next thing that the timing computer sends is a control byte for each digit. Because the event and heat scoreboard only has 6 digits, there will only be 6 control bytes. The control byte controls whether the decimal point is on or off and tells whether to display special or regular characters. See figure 3 for the bit breakdown of the control byte.

Figure 3: Control Byte Configuration



Once a control byte has been sent for each digit, the timing computer sends the address byte again, this time with the least significant bit a ‘0’ instead of a ‘1’. This signals that the following bytes are going to be digit data, not control data. The digit data byte tells the scoreboard what numeral to display and which digit to display it on, see figure 4 for the digit byte breakdown.

Figure 4: Digit Byte Configuration

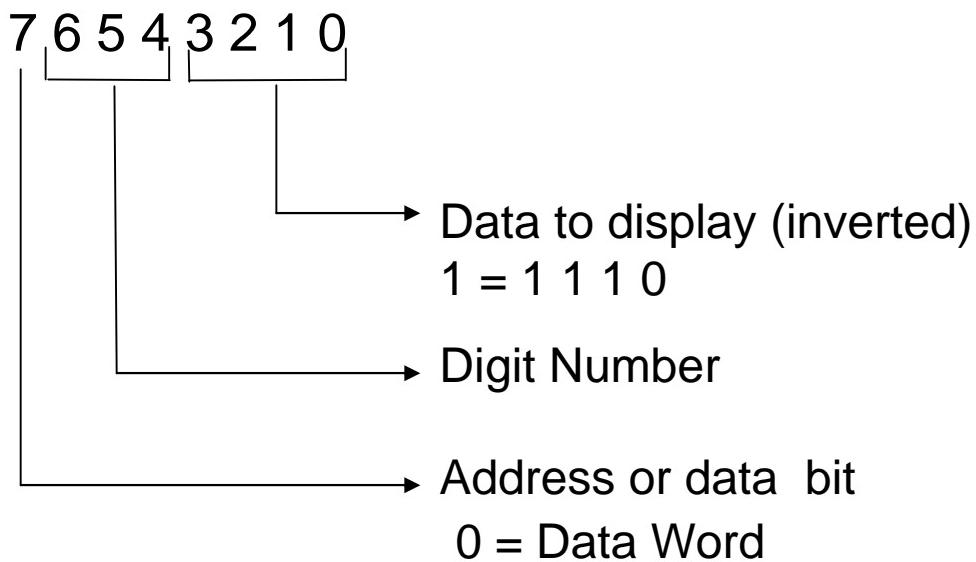


Table 1 displays an example of the bytes sent to display event 1 heat 1, event 1 heat 2, event 1 heat 3, event 2 heat 1, event 2 heat 2, and event 11 heat 1. The highlighted bytes are the only bytes that change from column to column.

Table 1: Bytes Sent

E1 H1	E1 H2	E1 H3	E2 H1	E2 H2	E11 H1
0xA7	0xA7	0xA7	0xA7	0xA7	0xA7
0x0F	0x0F	0x0F	0x0F	0x0F	0x0F
0x1F	0x1F	0x1F	0x1F	0x1F	0x1F
0x2F	0x2F	0x2F	0x2F	0x2F	0x2F
0x3F	0x3F	0x3F	0x3F	0x3F	0x3F
0x4F	0x4F	0x4F	0x4F	0x4F	0x4F
0x5F	0x5F	0x5F	0x5F	0x5F	0x5F
0xA6	0xA6	0xA6	0xA6	0xA6	0xA6
0x00	0x00	0x00	0x00	0x00	0x00
0x10	0x10	0x10	0x10	0x10	0x1E
0x2E	0x2E	0x2E	0x2D	0x2D	0x2E
0x30	0x30	0x30	0x30	0x30	0x30
0x40	0x40	0x40	0x40	0x40	0x40
0x5E	0x5D	0x5C	0x5E	0x5D	0x5E

3.2 Receiving the Data

In order to receive the data stream, the microcontroller was setup to receive a serial signal with the same parameters as the timing computer; 9600 BAUD, 8 data bits, 1 stop bit and even parity. The next step was to properly connect the datastream coming from the timing computer to the microcontroller. The existing scoreboard has a “data out” phono plug port. This port contains the un-modified data-stream output by the timing computer. This phono output port consists of 2 wires, a transmit and a ground wire. We tapped into this by attaching a male phono jack to another 2 strand cable, and then connecting the ground signal to the Rabbits’ ground, and the transmit signal to the RXB pin on the rabbit. The RXB pin is the serial port B, receive connection.

Every time a byte is received it triggers an interrupt and gets stored in a received buffer. When a byte is put into the received buffer, it is checked to see if is equal to 0xA6, which means channel 0C, digit data to follow. If it is, then the next 8 bytes coming from the timing computer are captured into a generic array to hold them while the decoding operations are taking place.

If a value greater than 0x7F is received before 8 bytes have been captured after 0xA6, the channel was interrupted and this value is the new channel. Any stored bytes are discarded, and the Rabbit will wait for the next 0xA6 to come by. 0x7F was chosen as the cutoff value because of the way the timing computer sends data. At the very most, the timing computer will never send data for more than 8 digits. Since the digit number is contained in the most significant digit of the hex number, anything over 0x7F is greater than the number of digits supported, and therefore must be a new channel number.

3.3 Event & Heat Extraction

When 8 bytes are received after 0xA6, and none of them are greater than 0x7F, the event and heat extraction function is called. The extraction function goes through the array containing the 8 digit data bytes and performs comparisons on them. If the byte is less than 16, we know it is for digit 0, if it is between 16 and 32 we know it is for digit 1, if it's between 32 and 48 it is for digit 2 and so on. A series of *if* statements are used to make these comparisons and determine which digit the byte contains data for.. Once inside the proper ‘if’ statement, the byte is sent to the compute_numeral function that returns the appropriate decimal value.

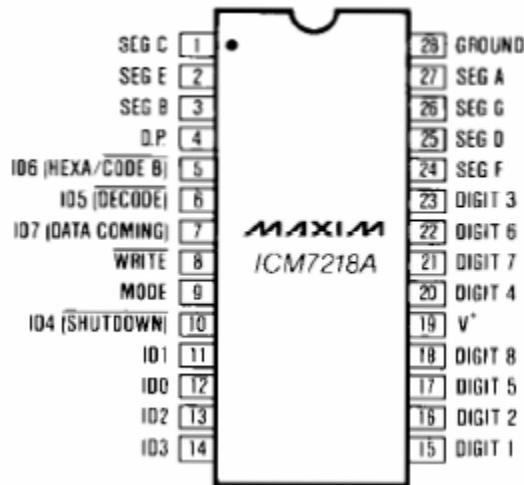
The compute_numeral function first mod’s the byte with 16 to get the remainder and get rid of the digit number part. The remainder is then the inverted binary equivalent

of the decimal numeral. A series of switch/case statements quickly turns this inverted binary number into the proper decimal equivalent. This is then returned to the parent function which multiplies it by 100, 10, or 1 (depending on the digit number) and adds it to the appropriate temporary heat or event number. We know which one to multiply by, because the *if* statements pick out which digit that the byte is for. Only the first 3 bytes and the last 3 bytes are used. The first 3 bytes contain the event number, and the last 3 bytes contain the heat number.

3.4 Maxim Operation

To display the data sent from microcontroller a Maxim 7218A display driver was used. The chip communicates with the microcontroller with a ten pin serial interface. In Figure , below, you can see the interface pins. These pins are MODE for loading control word, WRITE for input loaded into memory, and ID0-ID9 for address, control word, and data in.

Figure 5: Maxim 7218A Pin Out



Maxim display driver has 10 inputs and 16 outputs. Inputs are MODE, WRITE, ID0-ID7. Outputs are DIGIT1-DIGIT8, SEG A-SEG G and D.P. Maxim display driver is common Anode driver what powers Vcc pin and grounds segments that we want to turn on. The segments are common to all digits cycles through the power to every digit.

3.4.1 Format of Maxim

Table 2: Input Definition of Maxim

INPUT	PIN	STATE	FUNCTION
WRITE	8	High Low	Input Not Loaded Into Memory Input Loaded Into Memory
MODE	9	High Low	Loads Control Word on WR Loads Input Data on WR
ID0-ID2, DIGIT ADDRESS	12, 11, 13	High Low	Loads "one" Loads "zero"
ID3, BANK SELECT	14	High Low	Select RAM Bank A (Hex or Code B Select RAM Bank B Data only)
ID4, SHUTDOWN (MODE High)	10	High Low	Normal Operation Shutdown
ID5, DECODE/NO DECODE (MODE High)	6	High Low	No Decode Decode
ID6, HEX/CODE B (MODE High)	5	High Low	Hexadecimal Decoding Code B Decoding
ID7, DATA COMING (MODE High)	7	High Low	Data Coming (control word) No Data Coming (control word)
ID0-ID7, INPUT DATA (MODE Low)	5-7, 10-14	High Low	Loads "one" (Note 1) Loads "zero" (Note 1)

ID0-ID2 are used for a digit address when MODE is high and WRITE is low.

ID0-ID7 are used for actual input data when MODE is low and WRITE is low. When MODE is high and WRITE is low, ID3-ID7 are used for control word. These control words are ID3(BANK SELECT) for selecting RAM bank, ID4(SHUTDOWN) for normal operation,

ID5(DECODE/NO DECODE) for decode, ID6(HEX/CODE B) for selecting decoder type, and ID7(DATA COMING) for allowing control word data coming.

3.4.2 Register Address

Maxim interfaces microprocessor to 7 segment numeric LED displays of up to 8 digits, but we need 7 segment numeric LED displays of 5 digits, 3 digits(digit1,digit2, and digit3) to display event number and 2 digits(digit4 and digit5) to display heat number.

The Maxim driver has digit registers. The digit registers are addressed directly so that individual digits can be updated and retain data.

Digit number is on ID0-ID2.

Table 3: Digit Addressing

DATA LINES			Selected Digit
ID2	ID1	ID0	
0	0	0	D1
0	0	1	D2
0	1	0	D3
0	1	1	D4
1	0	0	D5
1	0	1	D6
1	1	0	D7
1	1	1	D8

3.4.3 Data

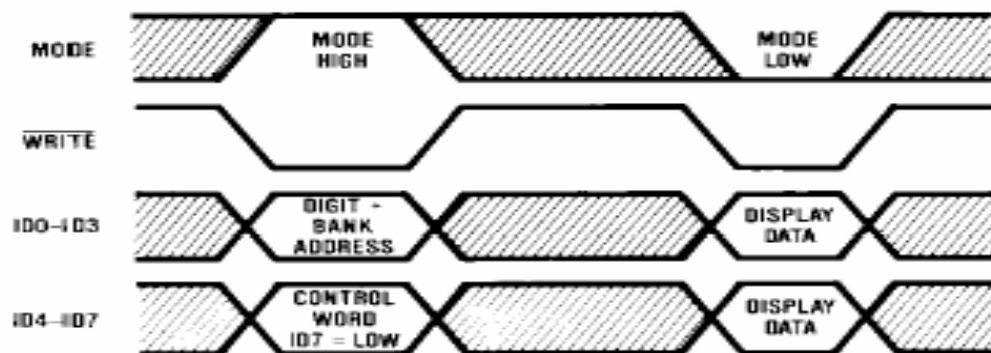
The actual numbers are sent on ID0-ID3. Actually the actual numbers are sent on ID0-ID7, but ID0-ID3 are for digits 0-9. ID4-ID7 are don't care digits. Either Hexadecimal or Code B decoder can be used as they are the same for digit 0-9. However, we used Code B to allow for blanks.

Table 4: Display Font

ID3	ID2	ID1	ID0	HEXADECIMAL	CODE B
0	0	0	0	0	0
0	0	0	1	1	1
0	0	1	0	2	2
0	0	1	1	3	3
0	1	0	0	4	4
0	1	0	1	5	5
0	1	1	0	6	6
0	1	1	1	7	7
1	0	0	0	8	8
1	0	0	1	9	9
1	0	1	0	A	-
1	0	1	1	B	E
1	1	0	0	C	H
1	1	0	1	D	L
1	1	1	0	E	P
1	1	1	1	F	(Blank)

3.4.4 Timing Diagram for Operating the Display Driver

Figure 6: Single Digit Update Timing



- Single digit data update mode

- One digit to be changed without updating the entire display
- Whenever heat and event number are changed, 5 digits are updated respectively

- First, the control register is updated with MODE high, Data coming low, and the address of the digit to be updated. Second, the actual data is transferred from ID0-ID7 into the selected digit's RAM location with MODE low.

3.4.5 Connection Rabbit with Maxim

- Rabbit microprocessor needs 10 input pins. We used 2 from port C, 3 from port D, and 5 from port E.

- ✓ MODE = pin9 on display driver, PD3 on rabbit
- ✓ WRITE = pin8 on display driver, PD4 on rabbit
- ✓ ID0 = pin12 on display driver, PD5 on rabbit
- ✓ ID1 = pin11 on display driver, PE0 on rabbit
- ✓ ID2 = pin13 on display driver, PE1 on rabbit
- ✓ ID3 = pin14 on display driver, PC0 on rabbit
- ✓ ID4 = pin10 on display driver, PE2 on rabbit
- ✓ ID5 = pin6 on display driver, PC2 on rabbit
- ✓ ID6 = pin5 on display driver, PE4 on rabbit

ID7 = pin7 on display driver, PE5 on rab

3.5 Maxim and 7 – Segment Display Setup

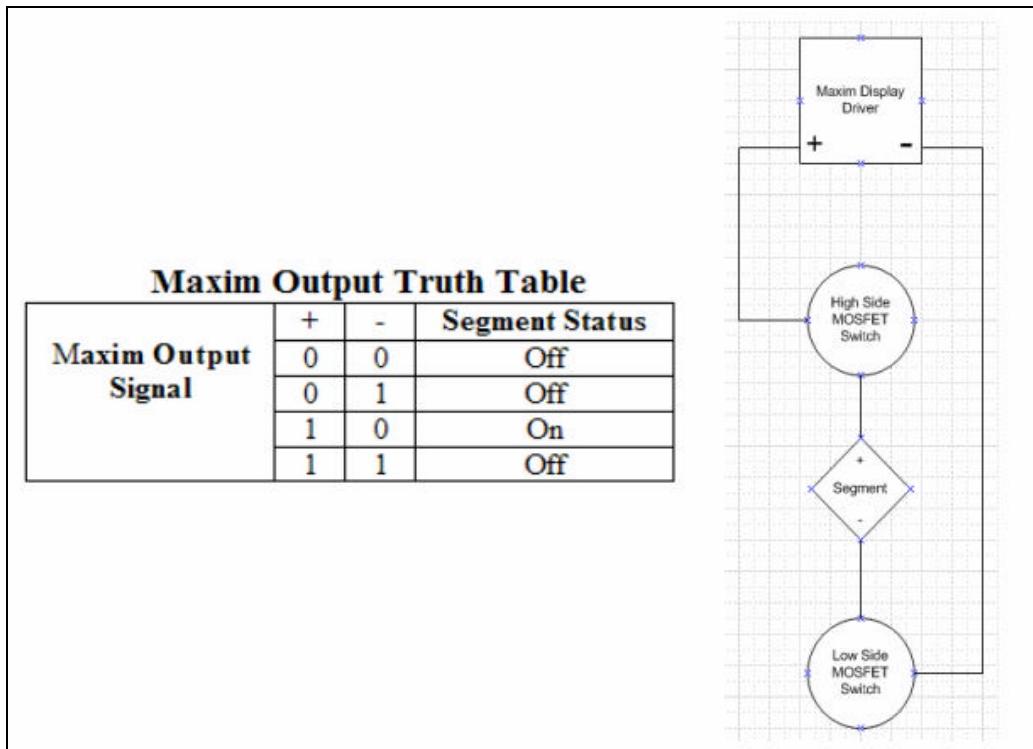
To display the data sent from the microcontroller a Maxim ICM7218A display driver was used. The chip communicates with the microcontroller with a ten pin serial interface. In Figure 5, above, you can see the interface pins. These pins are ID0-ID3, ID4 for shutdown mode, ID5 for decode, ID6 for HEX A/CodeB, ID7 for data coming, write, and mode.

The V+ pin is the 5V positive supply voltage. DIG1-DIG8 pins were to control each of the digits. The SEGA-SEGG pins were used to connect to each of the 7 segments. These connections would source current to the display segments. The chip was able to control each of the digits by constantly refreshing the digits. Once a digit is written it will hold that value until it changed by a new data stream. The refresh rate of the chip is so

fast that the human eye can't detect it therefore it looks as if it is always on, instead of blinking.

The 7 segment displays are common anode, which means that all the anodes are connected together and sending a low signal to each of the cathodes controls each of the segments. Each of the digits segment is made of 10 LED's in series. The height of each digit is 5 inches and the height of each segment is 2.5 inches. The maximum ratings for the 7 segment displays are as follows: The forward voltage per LED is 2 V at 20mA. Since the forward voltage per LED was 2.0 volts, we needed to use 24 volts at 15 mA for each digit to reach its maximum brightness. Since the Maxim driver digit output was 5 volts, the 24-volt source was switched using a MOSFET circuit that was controlled by the Maxim driver output signals.

Figure 7: Maxim Driver Output Flow Chart and Truth Table

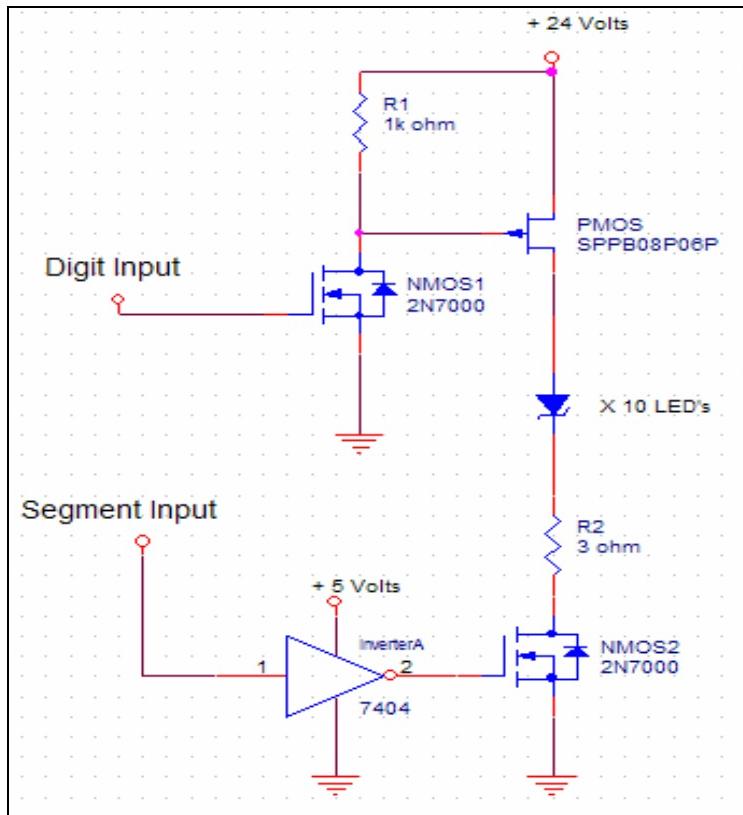


The way that the Maxim display driver controls the digits and segment is shown in figure 6. According to the truth table the only way that a segment will turn on is when the (+) digit output of the driver is high and when the (-) segment output is low. The MOSFET switch circuit will not respond to any other case.

3.5.1 MOSFET Switch Circuit

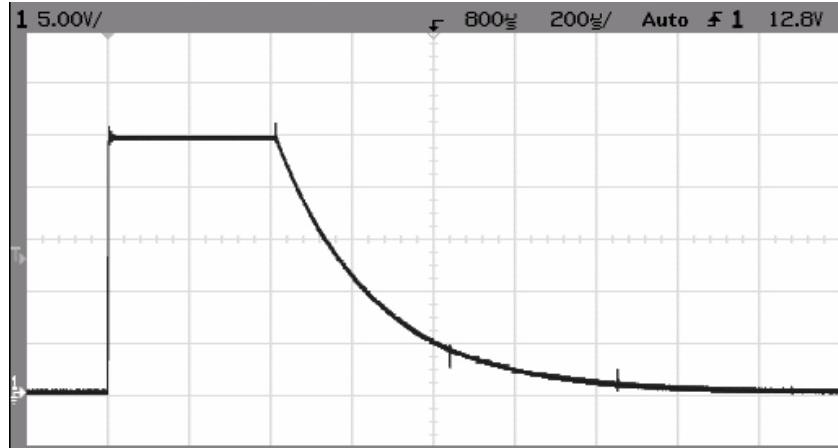
In order to switch sufficient power to the digits a MOSFET switch circuit was designed to control the voltage and current levels. The switch circuit was made of 2 2N7000 NMOS transistors, a SPPB08PO6P PMOS transistor, a logic inverter and 2 one-quarter watt resistors. This switch has a high side voltage of 24 volts, which is controlled by the Maxim driver digit and segment outputs. The following figure (Figure 8) shows the circuit diagram of the switch.

Figure 8: Mosfet Switch Schematic



The complete circuit contains five high side switches, for each of the digits; and seven low side switch, for each of the segments. When the MOSFET switch was initially designed, a 5 k ohm resistor was used for the resistance between the +24 volts and the PMOS gate. The only problem with this was that a large resistor along with the internal capacitance was creating a large (RC) time constant. This large time constant would lead to a ghosting effect on the digits as the Maxim driver cycled through the digits. The following figure (Figure 9) shows the voltage across the 5k resistor.

Figure 9: Scope View of 5k Resistor Voltage



As you can see it takes about 1 ms for the voltage to drop to zero. The ghosting effect on the digits can occur at voltages above 17 volts. From the figure it takes 0.09 ms for the voltage to drop below 17 volts. As the Maxim driver cycles through the digits the voltage level on the previous digit is still high enough, that the ghosting effect will occur.

To solve the ghosting effect a 1k resistor was exchanged for the 5k resistor. This made the RC time constant much smaller. The Time for the voltage across the resistor to reach zero was 0.2 ms, which was five times faster than the 5k resistor. Also it took about 0.03 ms for the voltage level to drop to 17 volts. Refer to Figure 10 for the voltage plot across the 1k resistor.

Figure 10: Scope View of 1k Resistor Voltage



4. Validation Procedures

4.1. Component Description's

4.1.1 Data Interceptor and Decoder

4.1.1.1 Component Description

The data interceptor and decoder is the component that will intercept the data coming from the timing computer and then extract the event and heat numbers from the data stream. This component consists of a connection to the data stream coming from the timing computer as well as software for the Rabbit microprocessor.

4.1.1.2 Interactivity

The data interceptor and decoder connects directly to the data stream from the timing computer via a serial connection that is physically plugged into the existing scoreboard. The existing scoreboard has a data out terminal that routs incoming data from the timing computer directly through to the next scoreboard in line. Our data interceptor will connect at this point. After extracting the appropriate event and heat number from this data stream it will send these numbers to the next component in line, the Send Data to Display Driver component.

4.1.1.3 Goal Objectives

This component will achieve the objectives of intercepting the data stream coming from the timing computer and extracting the event and heat information from that data.

4.1.2 Send Data to Maxim Driver.

4.1.2.1 Component Description.

The Send Data to Maxim Driver is the component that will send the data from the Rabbit microprocessor to Maxim driver. The Rabbit processor receives the event and heat number from the Interpreter and Decoder component. This Send Data to Maxim Driver component converts event and heat number to Maxim diver format and sends 10 bit serial data which contain register address and actual data.

4.1.2.2 Interactivity

The Maxim display driver interfaces the Rabbit microprocessor to a 5 digit 7 segment display. The Rabbit microprocessor sends converted data which contain control registers, register address, and actual data to Maxim driver. Converted data is for single digit update mode which allows one digit to be changed without updating the entire display. The each event and heat number is sent to maxim driver whenever event and heat number is updated from timing computer. In single digit update mode, first the control register is updated with MODE high, WRITE low, DATA COMING low, the desired data format, and the address of the digit to be updated on data lines. A second write to the Maxim driver, this time with MODE low, transfers the actual data into selected digit's RAM location. Whenever event and heat number is updated, single digit update occur five times for 3 digit event number and 2 digit heat number. After sending data, Maxim driver will drive 5 7-segment displays.

4.1.2.3 Goal Objectives

This components objective is to send data which contain control registers, register address, and actual data to Maxim driver. To send data to Maxim driver, the data from

timing computer should be converted to Maxim display format.

4.1.3 Transistor Switch Circuit

4.1.3.1. Component Description.

The transistor switch circuit handles the task of taking the 5-volt output control signal from the Maxim display driver and switches the 24-volt power supply to the 7-segment displays. This is necessary because the output of the Maxim is only 5 volts, which is much less than the voltage that the displays run at. This component consists of a NPN bipolar transistor and a 24-volt power supply.

4.1.3.2 Interactivity

The common anode of the 7-segment display is connected to the positive 24-volt supply and each segment is connected to the collector of each transistor. The emitter is connected to the negative of the voltage supply. The control voltage from the Maxim display driver is connected across the base and emitter. When the control signal from the display driver is sent to the transistor it sends current through the base-emitter and the transistor acts as a switch to connect the 24 volts to the 7-segment display.

4.1.3.3 Goal Objectives

This component's objective is to act as a switch to supply the necessary voltage to the 7-segment displays using the low voltage control signal from the display driver.

4.1.4 Seven Segment LED Displays.

4.1.4.1 Component Description.

The 7-segment displays are used to display the event and heat numbers that are generated from the timing computer. The displays are made up of 7-segments and each segment consists of 10 LED's that are in series. Due to the internal circuitry of the LED's each display needs 18 volts to bring the display to its brightest state. This supply voltage is high because the voltage drop across each diode is .7 volts and each LED needs about 1 volt to bring it to its brightest state.

4.1.4.2 Interactivity

Each display digit is connected to its respective transistor switch circuit depending on which digit it is. There are three digits used to display the event and two digits to display the heat. The common anode of each digit is connected to the positive voltage from the power supply and each segment is connected to the collector of each transistor. The circuit is then completed when the display driver sends the control signal to its respective digit, therefore displaying the correct event and heat numbers for the meet.

4.1.4.3 Goal Objectives

This components objective is to display the event and heat numbers that are generated from the timing computer. These displays must be bright enough to be read from about 100 feet so all the viewers can see them.

4.2 Testing and Verification Procedures

4.2.1 Data Interceptor and Decoder

To test the data interceptor and decoder component, the timing computer was going to be used to set up a practice swim event and change event and heat numbers. The data stream would be connected to the component and the data interceptor and decoder would work its magic. Unfortunately, the timing computer that was going to be used for testing broke, and with the main timing computer being used for swim meets, this was no longer a viable option.

Luckily, we were able to obtain sample data from the timing computer. With this sample data, a timing computer simulator was set up on another microcontroller and this would output data in the format of the timing computer. This data stream would be used to test the data interceptor and decoder.

To test the data interceptor and decoder component, the sample data stream coming from the timing computer simulator will be connected to the input of the data interceptor and decoder. The sample data stream will contain known values for the event and heat. Intermixed with these hex values will be hex values for other channels and random information. Also, the event and heat data will start to be sent, and then be interrupted by another channel, in order to see if the data interceptor and decoder can recover the proper event and heat numbers.

4.2.2 Send Data to Maxim Driver

To test the Send Data to Maxim Driver, The Rabbit microcontroller will be connected to the data interceptor and decoder and receive the current event and heat numbers. The Rabbit microcontroller also will be connected to the Maxim

microcontroller. The Rabbit microcontroller needs 10 I/O ports for output. The Maxim driver will receive the data from 10 I/O ports Rabbit microcontroller output. In order to see if the Maxim driver receives the proper event and heat numbers, the Maxim display driver will be connected to 5 digit 7-segment displays and 7-segment displays will display the data in proper numbers and positions.

4.2.3 Transistor Switch Circuit

To test the transistor switch circuit a series of voltages and current were ran through the collector and the base. These voltages were similar to the ones that are supplied by the display system. To test, an LED was connected from the supply voltage to the collector and a simulated control signal was sent to the base emitter. When the control signal was sent through the base the LED on the collector turned on, which means the circuit works as planned.

After the circuit performed to its expectations, it was tested for its maximum ratings. The maximum ratings that were used for the testing were way above the circuit's normal ratings. Therefore there is a huge margin or error if the circuit becomes unstable for some reason.

4.2.4 Seven Segment LED Displays.

The 7-segment displays were tested by running the rated current through each segment of each digit. This showed that the digits were not defective. The digits then were tested in the transistor switch circuit. As the control signal from the display driver was sent to the digit it would light up each of the corresponding digits. This test showed that the transistor switch circuit could in fact be used to run the digits from the low

voltage control signals from the display driver. After this was done there was not much else used to test the digits because a failure test was out of the question.

4.3. Validation Procedures

4.3.1 Data Interceptor and Decoder

In order to validate the results achieved from testing the data interceptor and decoder, the output of the function (the extracted event and heat numbers) will be compared with the event and heat numbers that were input. If this component is functioning properly, an incoming event and heat number should produce an identical outgoing event and heat number.

4.3.1.1 Objectives Met?

The objectives for the data interceptor and decoder component were:

- intercepting the data stream coming from the timing computer.
- extracting the event and heat information from that data.

The data interceptor and decoder met the objective of intercepting the data stream coming from the decoder. The data stream is input to the microcontroller via a serial connection at 9600 BAUD and even parity.

The data interceptor and decoder met the objective of extracting the event and heat information from the data stream. Even when the event and heat were interrupted, the component waited until they were fully sent again before updating the internal event and heat numbers.

4.3.2 Send Data to Maxim Driver

In order to validate the results achieved from testing the Send Data to Maxim Driver, the output of the component (the current event and heat numbers) will be displayed on 7-segment displays in proper numbers and positions.

4.3.2.1. Objectives Met?

The objectives for the Send Data to Maxim Driver were:

- converting Maxim display format
- sending data to Maxim driver.

The Send Data to Maxim Driver met the objective of converting Maxim display format. The control registers, register address and actual data for Maxim display driver are set.

The Send Data to Maxim Driver met the objective of sending data to Maxim driver. The Rabbit microcontroller needs 10 I/O ports for output. The Maxim driver will receive the data from 10 I/O ports Rabbit microcontroller output.

4.3.3 Transistor Switch Circuit and Seven Segment LED Displays.

In order to validate the results achieved from transistor switch circuit and the 7-segment displays, the digits must be displaying the correct event and heat numbers. Also to validate the transistor circuit the display must be bright enough to be seen from about 200 feet away.

5. Manufacturing & Support

5.1 Product Life Cycle

The Swim Team Scoreboard Project has identified six stages in the product lifecycle of the event and heat display board:

1. Design & Development
2. Introduction
3. Growth
4. Maturity
5. Decline
6. Death

For each of these stages, we will answer

- Who are the customers or users?
- What support will they need?
- What needs, concerns, problems will they face?
- What issues affect support costs?
- How can product revenue be maximized?
- What effect do design choices have on the PLC?

As a brief refresher, the event and heat display board will be attached to the existing scoreboard, and will rely on data coming from the timing computer in order to find the current event and heat numbers, and then display them continuously throughout the meet.

5.1.1 Design & Development

In the design and development stage, the event and heat scoreboard progressed from an idea, to a plan, to a functioning prototype, and from there to a useable product. There are no customers for this stage (besides the sponsor, who won't be using the product during the design and development stage), but the users are none other than ourselves. When we test each part of the finished product we will be using it, as well as the testing of the finished product to ensure functionality.

Since we are the design and construction team, the support we need will come in the form of advice and suggestions from our sponsor's and advisors. We also will utilize the manufacturer of the timing computer for information on the output of their system, so that we will be able to integrate our system with theirs appropriately.

As far as needs, concerns, and problems that we will encounter, they will all be design and manufacture related. Several big hurdles have presented themselves over the course of this project. The first was interpreting the data stream that emanates from the timing computer, finding out all the dirty little details about how it works, the format of the data, where the pertinent information was, etc. The next big hurdle was setting up a communications link between the outside world and our system, as well as the subparts of our system.

The support costs are entirely the cost of the equipment and supplies needed at this stage. Because we do not have a production-ready model, we have no incoming revenue, so it can't be maximized at this stage. One of the requirements laid out by the customer was to minimize the overall cost of this system. We have worked this in to the design, by going with a microcontroller that offered a one-time high cost for licensing and software, but the actual microcontroller product is fairly cheap if bought in quantity. The rest of the products that we decided to use are easily obtainable to allow for future replacement of worn-out or broken parts. We have also endeavored to minimize the number of individual parts in our system to maximize the total lifetime of our product.

5.1.2 Introduction to Market

In the introduction to market phase, the primary customer will be our sponsor, the Inland Empire Swimming Committee. After an initial trial and exposure at a swim meet,

the customers will be any of the swimming teams within the Inland Empire Swimming division, as well as any other teams with representatives present to view the operation of our system. The customer base will slowly grow as word spreads from team to team, although this will never be a high volume product, it could conceivably be sold in the thousands, eventually.

The initial customers should not need a lot of support. Another design consideration was to make this product as user friendly as possible. The theory of operation is to be able to plug in the power and the data line coming from the existing scoreboard and it will handle itself from there. Sufficient testing will have been performed on the system in the design phase to ensure full functionality and error free operation. In the unlikely event that something does go wrong, there are only 2 support options. Either a part needs to be replaced, or the code needs to be tweaked.

As far as needs, concerns, or problems that the initial customers will face, the product will be used in a hostile environment, e.g. high humidity, lots of transportation, possible rough handling, possible immersion, etc. Any of these situations could present a problem for our customer. If the event and heat display does break as a result of one or more of the above conditions, the likely culprit will be physical hardware. The software will survive, which is where most of the development cost would normally go to in this type of product.

The support costs at this stage will likely come from the failure of any hardware that would need to be replaced. Although unlikely, it is possible that some small costs could be incurred by a need for further tweaking of the code, if the unit does not perform as expected, or if something slipped by in testing.

Product revenue can be maximized in the introduction to market phase by selling as many units as possible and putting out a good product in the first place. This should be one of the lower failure rate stages, although some failure is to be expected, the choices that we have made in hardware will minimize the total failure rate and thus maximize revenue and product life. These choices, as stated above, were to minimize the number of separate parts in the system and to use easily obtainable parts in the construction of our system.

5.2 Failure Modes, Effects, & Criticality Analysis

5.2.1 Reliability Analysis

5.2.1.1 Failure Rate Calculation Methods

We used the Relex Software provided in the laboratory to establish our numbers.

5.2.1.2 Failure Rate Calculations

Table 5 – Component Analysis shows the failure rate for the individual components in the display system. Four distinct components have been identified, the Rabbit, the Maxim Display Driver, 5 separate seven segment displays, and a pull down resistor.

Table 5 : Component Analysis

I) Part	Quantity	Failure Rate	Failure Rate %
Rabbit	1	0.015281	1.79%
Maxim Driver	1	0.004089	0.48%
Logic Inverter	2	0.006239	0.73%
PMOS	5	0.046724	5.47%
NMOS	12	0.112138	13.12%
Resistor	12	0.000211	0.00%
Capacitor	2	0.006911	0.81%
LED's	350	0.663399	77.61%

Table 6 – MTBF shows the mean time between failure rating for the combined event and heat display system.

Table 6: MTBF

Failure Rate	0.039144
MTBF (hours)	2.55E+07
Reliability	0.999996

5.2.2 Failure Modes, Effects and Criticality Analysis

5.2.2.1 Potential Failure Modes

There are a variety of failure modes and causes of failure that have been identified. Table 7 – Possible Failure Modes, illustrates the possibilities that could occur.

Table 7: Possible Failure Modes

Possible Failure Modes	
1)	Cable not plugged in
2)	Internal connection loose
3}	Internal connection broken
4)	Inadequate power
5}	Display segment failure
6}	Unknown data input
7)	Submersion (in a pool)
8}	Dropping
9}	Display Digit Failure
10}	Microcontroller Failure
11}	Code misinterpretation
12)	Code failure
13}	Display Driver Failure

The possibilities are fairly straight forward, several require further explanation. Number 5, display segment failure is if 1 or more segments on a single digit fail.

Number 9, display digit failure concerns if 1 or more entire digits fail. Number 11, code misinterpretation considers the case where the code grabs the wrong address and outputs a wrong event and heat number, whereas number 12, code failure deals with the case that the code stops working entirely.

5.2.2.2 Severity Rating

To assign a rating for the severity of each possibility, Table 8 – Rating Scale was used. This table comes from Dale Anderson, Ph.D. in a paper dealing with failures.

Table 8: Rating Scale

Table 1. Rating Scale for Failure Effect Severity				
Rating	Description	Effect on System or Customer	Potential for Property Damage	Potential Hazard
1	Not noticeable	almost none	almost none	almost none
2	Very minor	noticeable	almost none	almost none
3	Minor	customer annoyed	almost none	almost none
4	Slight	customer annoyed system needs service	almost none	almost none
5	Moderate	customer complains system needs service	minor	slight
6	Significant	customer complains partial system malfunction	moderate	slight
7	Major	customer dissatisfied major system malfunction	significant	minor injury
8	Extreme	system inoperable or unfit for use	major	injury
9	Critical	system inoperable or unfit for use	extreme	serious injury
10	Hazardous	system inoperable or unfit for use	extreme	life threatening injury

Table 9 – Severity Rating, shows each failure mode with its corresponding failure rating, notice that some are higher than others.

Table 9: Severity Rating

Failure Mode	Severity Rating
1) Cable not plugged in	4
2) Internal connection loose	5
3} Internal connection broken	6
4) Inadequate power	5
5} Display segment failure	3
6} Unknown data input	4
7) Submersion (in a pool}	10
8} Dropping	7
9} Display Digit Failure	6
10} Microcontroller Failure	8
11} Code misinterpretation	3
12) Code failure	6
13} Display Driver Failure	6

5.2.2.3 Probability Occurrence

Due to the lack of actual probability data, the following levels have been used to assign a value for the likelihood of occurrence:

- 10 - Level A – Frequent,
- 8 - Level B – Reasonably probable,
- 6 - Level C – Occasional,
- 4 - Level D – Remote,
- 2 - Level E – Extremely Unlikely.

In the following section on RPN, the numbers preceding each level will be used to calculate the RPN. Table VI – Probability of Occurrence, shows the likelihood of each failure mode occurring.

Table 10: Probability of Occurrence

Failure Mode	Likelihood Level
1) Cable not plugged in	B
2) Internal connection loose	D
3} Internal connection broken	D
4) Inadequate power	D
5} Display segment failure	D
6} Unknown data input	D
7) Submersion (in a pool)	D
8} Dropping	C
9} Display Digit Failure	D
10} Microcontroller Failure	E
11} Code misinterpretation	D
12) Code failure	D
13} Display Driver Failure	D

5.2.2.4 Detection Rating

This section details the probability of detecting any of the possible failure modes that could occur. Table 11 comes from Doctor Anderson again, given in his paper on failures. Table 11 shows the rating scale for detecting failures.

Table 11: Detection Rating

Table 3. Rating Scale for Probability of Failure Detection		
Rating	In Service	Manufacturing QC
1	Almost certain	100% automatic inspection (SPC) + routine calibration & maintenance
2	Very high	100% automatic inspection (SPC)
3	High	100% SPC ($C_{pk} \geq 1.33$)
4	Moderately high	100% SPC
5	Moderate	some SPC plus 100% final inspection
6	Low	100% manual inspection using go/no-go gauges
7	Slight	100% manual inspection in the process
8	Remote	samples inspected, 100% no defects
9	Very remote	samples inspected by acceptable quality level
10	Almost none	no inspection

Table 12 – Failure Detection illustrates the possibilities of detecting each of the failure modes.

Table 12: Detection Likelihood

Failure Mode	Detection Likelihood
1) Cable not plugged in	2
2) Internal connection loose	5
3} Internal connection broken	4
4) Inadequate power	7
5} Display segment failure	2
6} Unknown data input	3
7) Submersion (in a pool)	1
8} Dropping	1
9} Display Digit Failure	1
10} Microcontroller Failure	2
11} Code misinterpretation	6
12) Code failure	4
13} Display Driver Failure	3

5.2.2.5 RPN

The final part of this Analysis is the Risk Priority Number (RPN). The RPN illustrates the failure modes that present the most risk to the system. Table IX – RPN Calculations shows the failure modes in descending order with the greatest RPN shown first. The RPN is calculated by multiplying the failure severity rating by the probability of occurrence, by the probability of detection. Remember for the probability of occurrence, a modified ranking has been used, as described above.

Table 13: RPN - Calculations

Failure Mode	Failure Severity	Occurrence Likelihood	Detection Likelihood
1) Cable not plugged in	4	8	2
2) Internal connection loose	5	4	5
3} Internal connection broken	6	4	4
4) Inadequate power	5	4	7
5} Display segment failure	3	4	2
6} Unknown data input	4	4	3
7) Submersion (in a pool)	10	4	1
8} Dropping	7	6	1
9} Display Digit Failure	6	4	1
10} Microcontroller Failure	8	2	2
11} Code misinterpretation	3	4	6
12) Code failure	6	4	4
13} Display Driver Failure	6	4	3

Table X – RPN, shows the final RPN values according to rank.

Table 14: RPN

Failure Mode	RPN
1) Inadequate power	140
2) Internal connection loose	100
3} Internal connection broken	96
4) Code failure	96
5} Code misinterpretation	72
6} Display Driver Failure	72
7) Cable not plugged in	64
8} Unknown data input	48
9} Dropping	42
10) Submersion (in a pool}	40
11} Microcontroller Failure	32
12} Display segment failure	24
13} Display Digit Failure	24

5.3 Societal Concerns

The only concerns are that the 24V power supply will supply enough current (5A) that it could be a hazard if misused. Also, if the display board is submerged or dropped in a pool, electrocution, while unlikely, could possibly result.

In order to make the display board more rugged, a printed circuit board should be developed. This will result in a decrease in the number of required wires for the entire system. Also, the wires that still remain can be either encased in round cable wrap or replaced with some type of wire strip, and the ends could even be sauderd on.

Appendix A – Specifications

Inputs:

- RS232 Input via ¼” phono plug
 - 9600 Baud
 - Even Parity
 - 8 data bits
 - 1 stop bit
- 120V AC input

Outputs:

None

Physical:

- Maxim 7218A Common Anode Display Driver
- Rabbit RCM2200
- 5 – 5” 7-Segment Displays
- 5 – PMOS SPP08P06P TO-220 Package
- 12 – NMOS 2N7000 TO-92 Package
- SN7404 Logic Inverter
- 24V Power Supply

Electrical:

- Rabbit Microcontroller & Proto-Board – 12V DC
- Maxim Display Driver – 5V DC
- Logic Inverter – 5V DC
- Mosfet High Side Switch – 24V DC
- Mosfet Control Signal – 0-5V DC

Appendix B – Bill of Materials

QNTY	Description	Price (\$)	Total (\$)
15	PMOS transistor	0.68	10.20
20	NMOS transistor	0.25	5.00
1	Special Shipping Charge	48.48	48.48
100	Cable Ends (female)	0.08	8.00
100	Cable Ends (male)	0.06	6.00
1	Misc. Supplies (tape, fasteners, etc.)	20.00	20.00
1	Rabbit RCM2200 & Protoboard	199.00	199.00
5	5" 7-Segment Displays	12.95	64.75
		Total:	361.43

Appendix C – Schematics, Drawings & Data Sheets

Appendix D – Test Data

Appendix E – Users Manual

I. Introduction

The purpose of this manual is to provide a basic overview and understanding of the event and heat display board. This manual will cover the installation and initial setup of the event and heat display board, as well as how to use it. Finally, and perhaps the most important aspect covered will be the troubleshooting section.

The event and heat display board is a simple device with only two inputs. The first is a phono plug for receiving data, and the second is a standard power plug that will work on any 120V AC standard wall outlet. The purpose of the display board is to continuously show the current event and heat numbers of a swim meet.

II. Installation

The installation process of the event and heat display board is remarkably simple. Since this display board is meant to be somewhat transportable, this installation topic will refer to setting up the display board at every new meet.

The first step in installing the event and heat display board is to connect the grey phono plug coming out of the device into either the Colorado System’s Timing Computer directly, or into the data output port of an existing scoreboard. The second step is to plug the power cord coming out of the device into either an extension cord coming from a wall outlet or directly into a wall outlet. Finally, ensure that the event and heat display board is in a secure, sturdy location.

III. Initial Setup

Like the Installation section, this Initial Setup section will reference the process that occurs whenever the display device is brought to a new meet. This means that the display board will need to be installed and setup multiple times.

After the installation procedures have been followed, and the timing computer is up and running, the display board is ready to go and should not require any more attention, other than to adjust the angle or location.

IV. Using the System

This display board will work with the Colorado Timing Systems System 4 or 5 timing computer, anything earlier or later has not been tested and is not guaranteed to work. The communications speed of the timing computer must be set at 9600 BAUD. If this is the case, the display board is ready to go and should be displaying the event and heat number that is on the timing computer.

The digits and digit driver are common anode type. This means that to turn on a segment, the digit's power pin is applied with 18V, and the segment(s) that we want on are grounded. The other segments are not grounded. As a result, each digit has 1 power wire going into it, along with 7 segment wires. The single power wire is unique to each digit, but all of the digits share the same segment wires.

The grey phono wire coming into the device is the data carrier. It contains only 2 separate wires. The black wire with the green tape around it is ground and can be connected to any available ground pin on the Rabbit (refer to figure 1). The other one is red and can be connected to only the RXB pin on the Rabbit. Again, refer to figure 1 for the location of these pins.

The Rabbit microcontroller needs to communicate with the Maxim display driver, so there are 10 short wires going from one part of the green board to another. These connections are somewhat colorcoded and the appropriate connections can be found by referring to Figure 1. The Maxim display driver then sends 5 digit outputs (the power signal) and 7 segment outputs to the amplifier circuits. The outputs of these amplifier circuits go directly to the digit's, either a power signal or a segment signal. Refer to Figure XX for the appropriate connections (color coded).

V. Troubleshooting

This troubleshooting section will identify the main and most likely problems that can occur, as well as the multiple causes and individual solutions for each problem.

Following is a list of problems covered in this section:

1. All digits are blank
2. The board only displays a ‘0’ for the event and a ‘0’ for the heat
3. 1 or more digits don’t turn on at all
4. Certain segments of the digits don’t turn on
5. A wire came loose

The table below, table I shows the problems as well as their various causes and solutions.

Table 15: Troubleshooting

Problem	Cause	Solution
All digits are blank	The power cord is not plugged in.	1. Make sure that the power cord coming from the display board is plugged in to a wall outlet.
	The internal outlet strip is turned off.	Reach in and flip the orange switch away from “Off”
	1 or both of the internal power cords are unplugged from the outlet strip	Carefully plug them back in and ensure that the outlet strip is turned on
	The small red & white striped wires coming from the 24V power supply are not connected to the circuits	Referring to Figure 1, carefully insert the loose power cable back into the appropriate place on the circuit board.
	All of the digit power wires	Referring to Figure 1, carefully

	are disconnected from the digit or the circuit.	insert the power wire back onto the appropriate digit pin or into the appropriate circuit location.
The board only displays a '0' for the event and a '0' for the heat	The grey phono cable coming from the display board is not connected to a valid datastream.	Connect it to the output port of an existing scoreboard, or if already connected to one, try a different one.
	The timing computer is not on.	Turn the Timing Computer on.
	The RXB or ground pin is not connected on the inside of the display.	Referring to Figure 1, connect the red wire coming out of the grey phono cable to the RXB pin on the Rabbit. Connect the black wire with Green tape to any available GRND pin on the Rabbit.
1 or more digits don't turn on at all	The event and/or heat number is not large enough.	If the event is less than 10, only the least significant digit will be on, the others will be blank. If the event is less than 100, only the 2 least significant digits will be turned on. The same goes for the heat.
	The digit power cable came loose.	Referring to Figure 1, connect the blank digits power wire to either the digit power pin, the output of the amplifier circuit, the input of the amplifier circuit (coming from the Maxim) or the output of the Maxim for that digit (going to the amplifier circuit)
Certain segments of the digits don't turn on	Those specific segment wires came loose.	Referring to Figure 1, trace the offending segment wire back from the digit, to the amplifier circuit output, to the amplifier circuit input, to the Maxim output and ensure that they are appropriately connected and none are loose.
	The segments turn on for certain digits, but not for others	Either the wire is off of some digits, or that digit's segment is burnt out.
A wire came loose		Identify what the wire is for, Refer to Figure 1 for help with this. Reconnect it. The wires will have color-coded tape on the

		ends, that should help in tracking down the appropriate location of the loose wire.
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Figure 1: Wire Connections

